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FORM PTO-1390 (REV 11-2000)	U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE	ATTORNEY'S DOCKET NUMBER 2490-14
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371		U.S. APPLICATION NO. (If known, see 37 C.F.R. 1.5) 09/937718 **Unassigned**
INTERNATIONAL APPLICATION NO. **PCT/GB00/01216**	INTERNATIONAL FILING DATE **30 March 2000**	PRIORITY DATE CLAIMED **31 March 1999**

TITLE OF INVENTION
ADAPTIVE FILTER EQUALISATION TECHNIQUES

APPLICANT(S) FOR DO/EO/US
WHITE et al

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below.
4. ☒ The U.S. has been elected by the expiration of 19 months from the priority date (Article 31).
5. A copy of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☐ is attached hereto (required only if not communicated by the International Bureau).
   b. ☐ has been communicated by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☐ is attached hereto.
   b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
7. ☐ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. ☐ are attached hereto (required only if not communicated by the International Bureau).
   b. ☐ have been communicated by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has **NOT** expired.
   d. ☐ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☐ A English language translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11 To 20 below concern document(s) or information included:

11. ☐ An Information Disclosure Statement under 37 C.F.R. 1.97 and 1.98.
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 C.F.R. 3.28 and 3.31 is included.
13. ☒ A FIRST preliminary amendment.
14. ☐ A SECOND or SUBSEQUENT preliminary amendment.
15. ☐ A substitute specification.
16. ☐ A change of power of attorney and/or address letter.
17. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821-1.825.
18. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).
19. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
20. ☐ Other items or information.

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U.S. APPLICATION NO. (If known, see 37 C.F.R. 1.5) 09/937718 Unassigned	INTERNATIONAL APPLICATION NO. PCT/GB00/01216	ATTORNEY'S DOCKET NUMBER 2490-14

21. ☒ The following fees are submitted:

BASIC NATIONAL FEE (37 C.F.R. 1.492(a)(1)-(5):

-- Neither international preliminary examination fee (37 C.F.R. 1.482) nor international search fee (37 C.F.R. 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO $1040.00

-- International preliminary examination fee (37 C.F.R. 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO....................$890.00

-- International preliminary examination fee (37 C.F.R. 1.482) not paid to USPTO but international search fee (37 C.F.R. 1.445(a)(2)) paid to USPTO........................$740.00

-- International preliminary examination fee (37 C.F.R. 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4)..............................$710.00

-- International preliminary examination fee (37 C.F.R. 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4).......................................$100.00

						CALCULATIONS		PTO USE ONLY
ENTER APPROPRIATE BASIC FEE AMOUNT =						$	1040.00	
Surcharge of $130.00 for furnishing the oath or declaration later than ☐ 20 ☒ 30 months from the earliest claimed priority date (37 C.F.R. 1.492(e)).						$	130.00	
CLAIMS	NUMBER FILED		NUMBER EXTRA	RATE				
Total Claims	16	-20 =	0	X	$18.00	$	0.00	
Independent Claims	3	-3 =	0	X	$84.00		0.00	
MULTIPLE DEPENDENT CLAIMS(S) (if applicable)				$280.00		$	0.00	
TOTAL OF ABOVE CALCULATIONS =						$	**1170.00**	
☐ Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2.							0.00	
SUBTOTAL =						$	**1170.00**	
Processing fee of $130.00, for furnishing the English Translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 C.F.R. 1.492(f)). +							0.00	
TOTAL NATIONAL FEE =						$	**1170.00**	
Fee for recording the enclosed assignment (37 C.F.R. 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 C.F.R. 3.28, 3.31). **$40.00** per property +						$	0.00	
Fee for Petition to Revive Unintentionally Abandoned Application ($1280.00 – Small Entity = $640.00)						$	0.00	
TOTAL FEES ENCLOSED =						$	**1170.00**	
						Amount to be: refunded	$	
						Charged	$	

a. ☒ A check in the amount of $1170.00 to cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account No. 14-1140 in the amount of $_____ to cover the above fees. A duplicate copy of this form is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 14-1140. A duplicate copy of this form is enclosed.

d. ☒ The entire content of the foreign application(s), referred to in this application is/are hereby incorporated by reference in this application.

NOTE: Where an appropriate time limit under 37 C.F.R. 1.494 or 1.495 has not been met, a petition to revive (37 C.F.R. 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

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29,009 October 1, 2001
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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of

WHITE et al | Atty. Ref.: 2490-14

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For: ADAPTIVE FILTER EQUALISATION TECHNIQUES

* * * * * * * * * * *

October 1, 2001

Assistant Commissioner for Patents
Washington, DC 20231

Sir:

PRELIMINARY AMENDMENT

Please amend the above application as follows:

IN THE CLAIMS

Please substitute the following amended claims for corresponding claims previously presented. A copy of the amended claims showing current revisions is attached.

8. (Amended) A switch as claimed in claim 5, , wherein the input and output waveguides intersect at an angle of substantially 90 degrees.

9. (Amended) A switch claimed in claim 5 wherein the first and second upper waveguides are of the same width as the input and output waveguides respectively.

10. (Amended) A switch as claimed in claim 5, wherein the first and second upper waveguides are not of the same thickness as the input and output waveguides respectively.

11. (Amended) A switch structure as claimed in claim 5, wherein the first and second upper waveguides are of the same thickness as the input and output waveguides respectively.

12. (Amended) A switch as claimed in claim 5, wherein the axis of the first and second upper waveguides are centred above the axis of the input and output waveguides respectively.

13. (Amended) A switch as claimed in claim 5, wherein the axis of the first and second upper waveguides are not centred above the axis of the input and output waveguides respectively.

14. (Amended) A switch as claimed in claim 5, wherein the first and second upper waveguides and/or the input and output waveguides are not of constant width and/or constant thickness.

15. (Amended) A switch as claimed in claim 5, formed on a substrate material which is substantially planar.

16. (Amended) A switch as claimed in claim 5, wherein the waveguides are terminated by end facets that are not perpendicular to the waveguide axis.

17. (Amended) An array of switches each switch being as claimed in claim 5.

REMARKS

The above amendments have been made to place the application in better form for allowance. Attached hereto is a marked-up version of the changes made to the claims by the current amendment. The attached page(s) is captioned "**Version With Markings To Show Changes Made**."

Respectfully submitted,

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VERSION WITH MARKINGS TO SHOW CHANGES MADE

IN THE CLAIMS

8. (Amended) A switch as claimed in claim 5, [6 or 7], wherein the input and output waveguides intersect at an angle of substantially 90 degrees.

9. (Amended) A switch claimed in [any one of claims 5 to 8] claim 5 wherein the first and second upper waveguides are of the same width as the input and output waveguides respectively.

10. (Amended) A switch as claimed in [any one of claims 5 to 9] claim 5, wherein the first and second upper waveguides are not of the same thickness as the input and output waveguides respectively.

11. (Amended) A switch structure as claimed in [any one of claims 5 to 9] claim 5, wherein the first and second upper waveguides are of the same thickness as the input and output waveguides respectively.

12. (Amended) A switch as claimed in [any one of claims 5 to 11] claim 5, wherein the axis of the first and second upper waveguides are centred above the axis of the input and output waveguides respectively.

13. (Amended) A switch as claimed in [any one of claims 5 to 11] claim 5, wherein the axis of the first and second upper waveguides are not centred above the axis of the input and output waveguides respectively.

14. (Amended) A switch as claimed in [any one of claims 5 to 13] claim 5, wherein the first and second upper waveguides and/or the input and output waveguides are not of constant width and/or constant thickness.

15. (Amended) A switch as claimed in [any one of claims 5 to 14] claim 5, formed on a substrate material which is substantially planar.

16. (Amended) A switch as claimed in [any one of claims 5 to 15] claim 5, wherein the waveguides are terminated by end facets that are not perpendicular to the waveguide axis.

17. (Amended) An array of switches each switch being as claimed in [any one of claims 5 to 16] claim 5.

AN OPTICAL CROSSPOINT SWITCH USING VERTICALLY COUPLED WAVEGUIDE STRUCTURE

An optical crosspoint switch structure is disclosed. The switch permits light signals to be diverted from any of arbitrary number of input ports to any or several of an arbitrary number of output ports. The switch consists of two groups of intercepting optical waveguides formed on a planar substrate, which are the input and output waveguides respectively. At each intersection, another waveguide is formed above the input and output waveguides. Optical coupling between this upper waveguide and the input/output waveguides is controlled by an electrical or optical signal. The upper waveguide has a corner mirror at the intersection. When the control signal allows, light couples from the input waveguide to the upper waveguide. After being reflected by the corner mirror, the light couples from the upper waveguide into the output waveguide. The upper waveguide incorporates the active switching element, allowing high modulation depth and low crosstalk level.

FIELD OF INVENTION

The present invention relates to optical components and in particular to an optical crosspoint switch array structure.

DESCRIPTION OF THE RELATED ART

An optical crosspoint switch array is used in an optical communications system/network to route light signals. It allows light to be diverted from (1) any one of input ports to any one or more output ports (routing), (2) several input ports to an equal or lower

number of output ports in an arbitrary order (shuffling or combination), and, (3) any one input port to several output ports (broadcasting). The switch can have an arbitrary number of input and output ports and is designed to be readily scaleable. The realisation of these functions important applications in an optical communications network.

Three main kinds of conventional structures for optical crosspoint switches have been proposed. The first kind splits all optical inputs into a number of branches, as described by Kato, T., et al, in IEICE Trans. On Electronics, Vol.E82C, No.2 pp.305-312, 1999. The number of branches equals the number of outputs. Then it seeks to regroup and recombine these branches. Switching is performed by blocking these branches before recombination. The second kind uses two groups of perpendicular waveguides on a planar substrate as inputs and outputs, respectively. Switching is achieved by constructing couplers in the same plane, as described by Fish, G.A., et al, IEEE Photonics Technology Letters, Vol.10, No.2, pp.230-232, 1998. The third kind also uses two groups of perpendicular waveguides on a planar substrate as inputs and outputs, respectively. Switching is achieved by constructing directional couplers in the vertical direction using only refractive index change as the switching mechanism, as described in "analysis of an InGaAsP/InP twin-overlayed-waveguide switch" by R. Maciejko, A. Champagne, B. Reid, and H Mani, In IEEE Journal of Quantum Electronics, 1994, Vol.30, No.9, pp.2106-2113.

However, the first kind of structure has the disadvantages that it has a high insertion loss proportional to the number of outputs and that it uses large substrate area. The second kind of structure has

the disadvantages that it uses large substrate area. The third structure has the disadvantage that high modulation depths and low crosstalk levels are difficult to achieve.

SUMMARY OF THE INVENTION

The object of the present invention is to provide an optical crosspoint switch scheme employing vertical optical coupling with high modulation depth and minimum crosstalk levels between channels.

Another object of the present invention is to provide an optical crosspoint switch occupying a small area per crosspoint (input/output pair).

Still, another object of the present invention is to provide, but not limited to, one particular embodiment of the scheme, which utilises simultaneous refractive index and optical gain changes in the upper waveguide.

Still, another object of the present invention is to make possible, but not to limit to, another particular embodiment of the scheme, which utilises simultaneous refractive index and optical absorption changes in the waveguide coupler.

To achieve the object of the invention, as embodied and broadly described herein and illustrated in Fig. 1, two groups of intercepting waveguides, namely the input (01) and the output (02) waveguides, are formed on a planar substrate of an appropriate material. Near each crosspoint, another layer of waveguide is formed above the input and output waveguides, forming a vertically coupled waveguide

structure [VCWS(03)]. Vertical optical coupling between this upper waveguide and the lower input/output waveguides is controlled by an electric or optical signal. The upper waveguide has total internal reflection [TIR(04)] corner mirror at the crosspoint. When the control signal selects one particular switch, light couples from the input waveguide to the upper waveguide fully or partially. Reflected by the corner mirror, the light is steered by an angle, then couples from the upper waveguide into the output waveguide. High modulation depth and low crosstalk level are achieved by changing the optical absorption and/or gain in the waveguides synchronously with the switching action.

To achieve another object of the invention, the thickness and the refractive index of the lower layer, the upper waveguide layer and the spacing layer between them are designed so that the coupling length is reduced to the extent that the distance between adjacent ports is decided by the space needed for the input/output optical fibre coupling.

To achieve one particular embodiment of the invention, the lower waveguide, the spacing layer and the upper waveguide layer are consequently formed on a semiconductor substrate suitable for the signal wavelength, to produce a wafer. The bandgap of the lower waveguide is such that it is transparent at the signal wavelength. The bandgap of the upper waveguide is such that it provides high optical absorption when there is no carrier injection, and provides optical gain when there is carrier injection. The propagation constants of the two waveguides are so designed that, when there is no carrier injection, the lower waveguide has smaller propagation constant than the upper

waveguide. The doping profile of the layers ensures that most injected carriers are confined in the upper waveguide.

To achieve another particular embodiment of the invention, the lower waveguide, the spacing layer and the upper waveguide layer are consequently formed on a III-V semiconductor substrate suitable for the signal wavelength, to produce a wafer. The bandgap of the lower waveguide is such that it is of low optical loss at the signal wavelength. The bandgap of the upper waveguide is such that it provides high optical absorption when there is applied electric field, and is of low optical loss when there is no applied electric field. The propagation constants of the two waveguides are so designed that, when there is no applied electric field, the two waveguides have equal propagation constants. The doping profile of the layers ensures that electric field will be applied mostly across the upper waveguide.

The objects and advantages of the invention will be set forth in part in the description which follows, and in part will be obvious from the description, or may be learnt by practice of the invention. The objects and advantages of the invention will be realised and attained by means of the elements and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

Fig. 1 illustrates the configuration of the optical crosspoint switch array with 2 inputs and 2 outputs, which can be extended to arbitrary numbers of inputs and outputs.

Figs. 2A and 2B illustrate schematically propagation of the light signal at each cross point with control signal at "on" and "off" states, respectively. A plan (top) view and a perspective view are included in each state.

Figs. 3A and 3B illustrate schematically propagation of the light signal in the first particular embodiment of the invention, with distributions of optical refractive index (n) and absorption in both "ON" and "OFF" states.

Figs. 4A and 4B illustrate schematically propagation of the light signal in the second particular embodiment of the invention, with distributions of optical refractive index (n) and absorption in both "ON" and "OFF" states.

Fig. 5 shows the layer structure of a wafer on which the array is fabricated.

Fig. 6 shows the layout of a 4x4 switch array.

Fig. 7 illustrates a switch unit cell.

Fig. 8 shows the switching characteristics of the switch unit cell.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be made in detail to the

preferred embodiments of the present invention, two examples of which are illustrated in accompanying drawings.

One preferred embodiment of the present invention will be explained hereinafter with references to the accompanying drawings.

At the "ON" state, carriers are injected into, and confined in the upper waveguide of Fig. 3. The upper waveguide may comprise bulk or quantum-well III-V semiconductor material such as InGaAsP, which, at the signal light wavelength, provides optical gain with adequate non-equilibrium carrier concentration but is highly absorptive when there is no such carrier concentration. The refractive index of the upper waveguide at the signal wavelength will be reduced due to the existence of these carriers, causing the reduction of the propagation constant of the upper waveguide to a value close to that of the lower waveguide. As a result, strong optical coupling happens between the two waveguides, enabling the transfer of signal from the lower input waveguide to the upper waveguide, and after reflected by the corner mirror, its transfer from the upper waveguide to the lower output waveguide. At the "OFF" state, there is no injected carrier, the unequal propagation constant of the two waveguide layers reduce optical coupling to a weak extent. In the absence of injected carriers, high optical absorption in the upper waveguide ensures that the weak signal light that does couple into the upper waveguide is absorbed and does not couple into the output waveguide. High modulation depth and low crosstalk level is therefore achieved. This embodiment of the invention has the additional advantage of providing optical gain to compensate for the losses

which may occur in the crosspoint switch or other parts of the optical transmission link.

Another preferred embodiment of the present invention will be explained hereinafter with references to the accompanying drawings.

At the "ON" state, no electric field is applied across the upper waveguide of Fig. 4. As a result, strong optical coupling happens between the two waveguides because of their equal optical propagation constants, enabling the transfer of signal from the lower input waveguide to the upper waveguide, and after reflected by the corner mirror, its transfer from the upper waveguide to the lower output waveguide. At the "OFF" state, an electric field is applied across the upper waveguide, increasing both its refractive index (therefore its optical propagation constant) and its absorption. The unequal propagation constant of the two waveguide layers reduce optical coupling to a weak extent. The high optical absorption in the upper waveguide ensures that the weak signal light that does couple into the upper waveguide is absorbed and does not couple into the output waveguide. High modulation depth and low crosstalk level is therefore achieved.

Other embodiments of the invention will be apparent to the skilled in the art from consideration of the specification and practice of the invention disclosed herein. It is intended that the specification and examples be considered as exemplary only, with the true scope and spirit of the invention defined by the claims.

An optical crosspoint switch array combining such features as compactness, high speed, and low crosstalk

level is highly desirable in high speed all-optical networks. Demonstrated devices based on various guided-wave components so far appear unable to achieve these qualities simultaneously. One kind of crosspoint switches employs MMI couplers to split all optical inputs into a number of branches. Then it seeks to regroup and recombine these branches. Switching is performed by blocking these branches before recombination. This kind of crosspoint switch has a high insertion loss proportional to the number of outputs and uses large substrate area. A second kind of switch uses two groups of perpendicular waveguides on a planar substrate as inputs and outputs, respectively. Switching is achieved by constructing directional couplers in the same plane, as described in. This also uses large substrate area. The present switch structure uses the coupling of light in the vertical direction (normal to the substrate plane, see Fig. 7. to switch any input signal orthogonally to any output (Fig. 8.) Ultra-low crosstalk level at the "OFF" state is achieved by rendering the coupler to a weakened coupling and a high absorption state simultaneously, so that any stray signal is sufficiently attenuated. By careful design, the couplers are made short, allowing the switch to be compact, but tolerant to fabrication variations. The component switch mechanism should allow switching on nanosecond timescales.

DEVICE DESIGN AND FABRICATION

The crosspoint switch array presented here is fabricated on a InGaAsP/InP wafer whose layer structure is illustrated in Fig. 5. It contains two waveguide layers which are grown by MOVPE on (100) InP substrate. The undoped upper waveguide core which contains 5

unstrained 65A InGaAs quantum wells with Q1.26 barriers serves as the active layer at the wavelength of 1550nm. To control the optical coupling between the two waveguide layers, the effective refractive index of passive lower waveguide core is adjusted to a suitable value lower than that of the active waveguide by incorporating an appropriate number of quantum wells of 37A thick. The passive waveguide has a low absorption for wavelengths of 1500nm and above. Both waveguide core layers are 0.3mm thick, separated by a 1.2mm thick InP spacing layer. The spacing layer and the passive waveguide core are n-doped to $3x10^{17}/cm^3$, as well as the lower InP cladding. The design of this is such that effective switching can be achieved over the entire gain bandwidth of ~50nm of the active layer. Two perpendicular groups of ridge waveguides are formed on the wafer as input and output waveguides, respectively. The waveguides in each group are 3mm wide and 250mm apart. At present 4x4 switch arrays are fabricated (Fig. 2) but it is easy to scale up to any input/output numbers. The upper active waveguide layer is removed from the waveguides except for a 200mm length extending from the intersections toward both the input and output ports, as illustrated in Fig. 3. Vertical optical directional couplers are formed between these active waveguide layer and the lower passive waveguide layer. A total internal reflection mirror (TIR), the depth of which penetrates the upper waveguide, is formed diagonally cross the waveguide intersection. Switching mechanism is provided by carrier induced refractive index changes in the active upper waveguide of the coupler, which change the coupling length of the vertical coupler [3]. At the "ON" state, the effective refractive index of the active upper waveguide is reduced to equal that of the lower waveguide by the presence of injected carriers, therefore the input

optical signal will couple strongly from the passive input waveguide into the upper active waveguide, reflected by the TIR, then couple from the upper waveguide to the output waveguide. The injected carriers also provide optical gain for the signal, therefore contributing the high ON/OFF contrats. Low crosstalk level at the "OFF" state (no carrier injection) is achieved by the combination of much weakened signal coupling into the active upper waveguide and the highly absorptive nature of the active upper waveguide to any residual coupled signal. At the OFF state the input light travels to the next unit cell through the lower passive waveguide. The structure is defined by a reactive ion etching process using H_2/CH_4 plasma. A combination of metal and dielectric mask materials are used to facilitate the two-level dry-etching, and to produce smooth and vertical sidewall finish required by the TIR. The depth of the TIR mirror is about halfway between the two waveguide layers. The structure is finished with Polyimide planitization and Ti/Au contacts. The arrays (Fig.3) are then cleaved from the wafer, allowing 100mm passive access waveguides at both input and output ports. Individual switches are also cleaved from the arrays for characterisation.

RESULTS:

Preliminary characterisation results is presented here for a single switch unit cell. The switch cell has 100mm input and output passive waveguides, with the input waveguide extending beyond the intersection for 500mm. An HP8168E tuneable laser source is used to produce input signal in the wavelength range of 1470-1580nm. The signal is coupled in and out of the device via fibre lenses. A fibre polarisation controller is

used to produce either TE or TM polarised input signal. An optical filter is used to eliminate most of the spontaneous emission from the output signal.

The optimum switching characteristics, plotted in Fig. 8, is achieved at 1=1548nm (the gain peak wavelength of the active waveguide) with TE input polarisation. It is shown that in the "OFF" state, i.e., when injected current is zero, the measured crosstalk signal level is as low as -79dBm for an in-fibre input signal power of -5dBm. Accounting the total loss of about 14dB including input/output coupling and the optical filter, the on-chip crosstalk is about -60dB, which to our knowledge is the lowest reported so far. The ON/OFF contrast at 70mA is as high as 45dB while an maximum of >50dB is achieved for injection current of 160mA.

CONCLUSION

An compact integrated 4x4 optical crosspoint switch array has been fabricated on InGaAsP/InP substrate which employs active vertical couplers to achieve compactness, low crosstalk level and high ON/OFF contrasts. Preliminary results show that the switches can achieve on-chip crosstalk levels as low as -60dB and a high ON/OFF contrast of greater than 50dB. The switching time for the device is being tested and is believed to be in the nanosecond range determined by the carrier lifetime. Further results will be presented at the conference.

4x4 optical crosspoint switch arrays based on the first preferred embodiment and the second preferred embodiment have been designed, fabricated and tested. The devices are fabricated on InP substrate. The area

of a 4x4 array is only 1.2x1.2mm, with an distance of 0.25mm between adjacent input or output waveguides. The crosstalk level at input wavelength of 1548nm is -60dB. The modulation depth (ON/OFF contrast) is 50dB. The fabrication and testing results are described in detail in the appending paper authored by the inventors.

CLAIMS

1. A method of controlling an optical crosspoint switch which comprises intersecting input and output waveguides forming an intersection, a first upper waveguide which is arranged adjacent to the input waveguide and which extends at least partially along the input waveguide to the intersection, a second upper waveguide which is arranged adjacent to the output waveguide and which extends at least partially along the output waveguide from the intersection, and a corner mirror located at the intersection for coupling light signals from the first upper waveguide to the second upper waveguide, the method characterized by the steps of:

in an OFF state of the switch, varying the refractive index profile of the input and output waveguides or of the first and second upper waveguides in order to prevent light transfer from occurring between the first and second upper waveguides and the input and output waveguides respectively; and

in the OFF state of the switch, varying the loss/gain characteristics of the input and output waveguides or of the first and second upper waveguides, thereby enhancing the prevention of light transfer between the first and second upper waveguides and the input and output waveguides respectively.

2. A method as claimed in claim 1, wherein the varying of the refractive index profile and loss/gain characteristics of the input and output waveguide or of the first and second waveguides comprises applying an electrical signal thereto.

3. A method of controlling an optical crosspoint switch which comprises intersecting input and output waveguides forming an intersection, a first upper waveguide which is arranged adjacent to the input waveguide and which extends at least partially along

the input waveguide to the intersection, a second upper waveguide which is arranged adjacent to the output waveguide and which extends at least partially along the output waveguide from the intersection, and a corner mirror located at the intersection for coupling light signals from the first upper waveguide to the second upper waveguide, the method characterized by the steps of:

in an ON state of the switch, varying the refractive index profile of the input and output waveguides or of the first and second upper waveguides in order to enable light transfer to occur between the first and second upper waveguides and the input and output waveguides respectively;

in the ON state of the switch, varying the loss/gain characteristics of the input and output waveguides or of the first and second upper waveguides, thereby enhancing light transfer between the first and second upper waveguides and the input and output waveguides respectively.

4. A method as claimed in claim 3, wherein the varying of the refractive index profile and loss/gain characteristics of the input and output waveguide or of the first and second waveguides comprises applying an electrical signal thereto.

5. An optical crosspoint switch comprising:

intersecting input and output waveguides forming an intersection;

a first upper waveguide arranged adjacent to the input waveguide and extending at least partially along the input waveguide to the intersection;

a second upper waveguide arranged adjacent to the output waveguide and extending at least partially along the output waveguide from the intersection; and

a corner mirror located at the intersection for coupling light signals from the first upper waveguide

into the second upper waveguide, characterised in that the input and output waveguides or the first and second upper waveguides are made of a material having characteristics such that application of an electric signal thereto causes variation of the loss/gain characteristics and refractive index profile thereof.

6. A switch as claimed in claim 5, wherein increases in the electrical signal cause increases in loss of the input and output waveguides or of the first and second upper waveguides.

7. A switch as claimed in claim 5, wherein increases in the electrical signal cause increases in gain of the input and output waveguides or of the first and second upper waveguides.

8. A switch as claimed in claim 5, 6 or 7, wherein the input and output waveguides intersect at an angle of substantially 90 degrees.

9. A switch claimed in any one of claims 5 to 8, wherein the first and second upper waveguides are of the same width as the input and output waveguides respectively.

10. A switch as claimed in any one of claims 5 to 9, wherein the first and second upper waveguides are not of the same thickness as the input and output waveguides respectively.

11. A switch structure as claimed in any one of claims 5 to 9, wherein the first and second upper waveguides are of the same thickness as the input and output waveguides respectively.

12. A switch as claimed in any one of claims 5 to 11, wherein the axis of the first and second upper waveguides are centred above the axis of the input and output waveguides respectively.

13. A switch as claimed in any one of claims 5 to 11, wherein the axis of the first and second upper waveguides are not centred above the axis of the input

and output waveguides respectively.

14. A switch as claimed in any one of claims 5 to 13, wherein the first and second upper waveguides and/or the input and output waveguides are not of constant width and/or constant thickness.

15. A switch as claimed in any one of the claims 5 to 14, formed on a substrate material which is substantially planar.

16. A switch as claimed in any one of claims 5 to 15, wherein the waveguides are terminated by end facets that are not perpendicular to the waveguide axis.

17. An array of switches each switch being as claimed in any one of claims 5 to 16.

18. An array of switches as claimed in claim 17, wherein the input and output waveguides have tapered ends to enhance coupling between the array and as optical fibre.

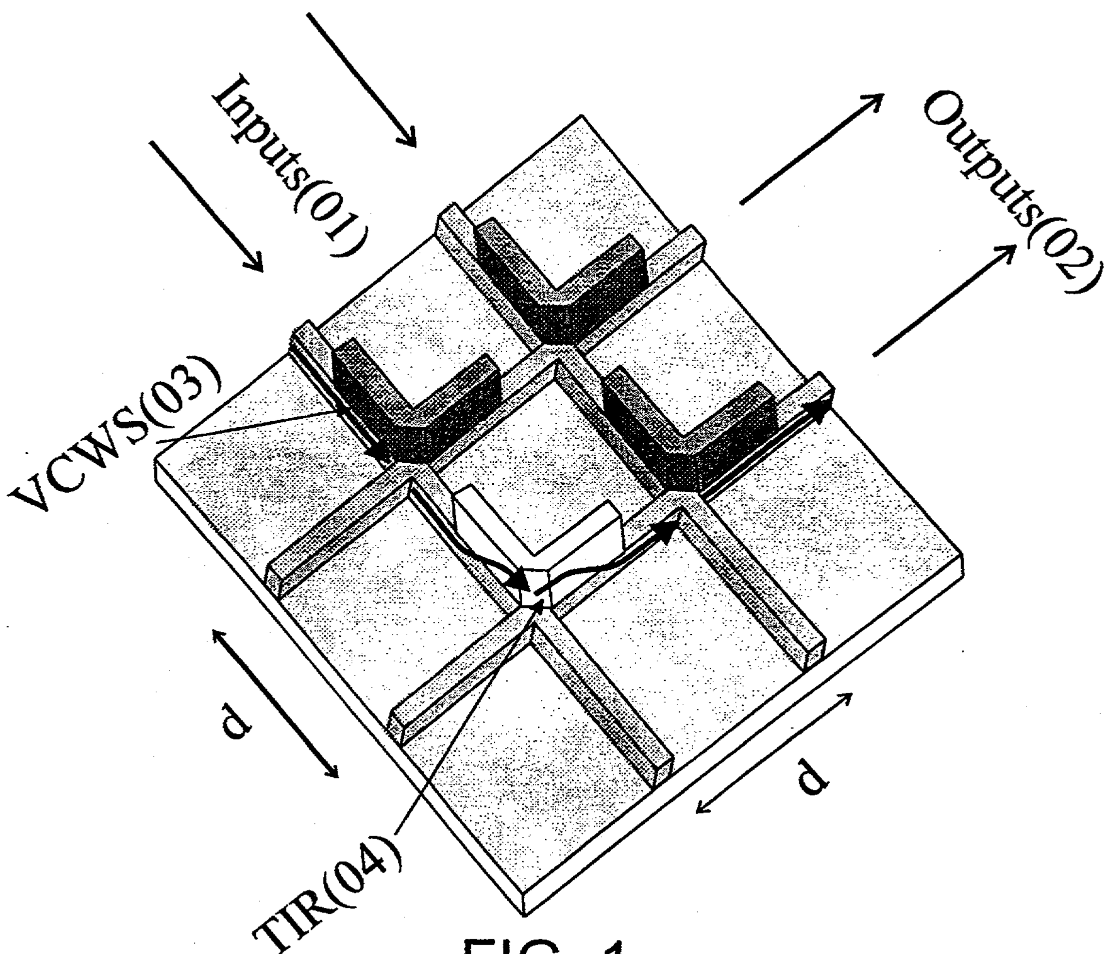

FIG. 1

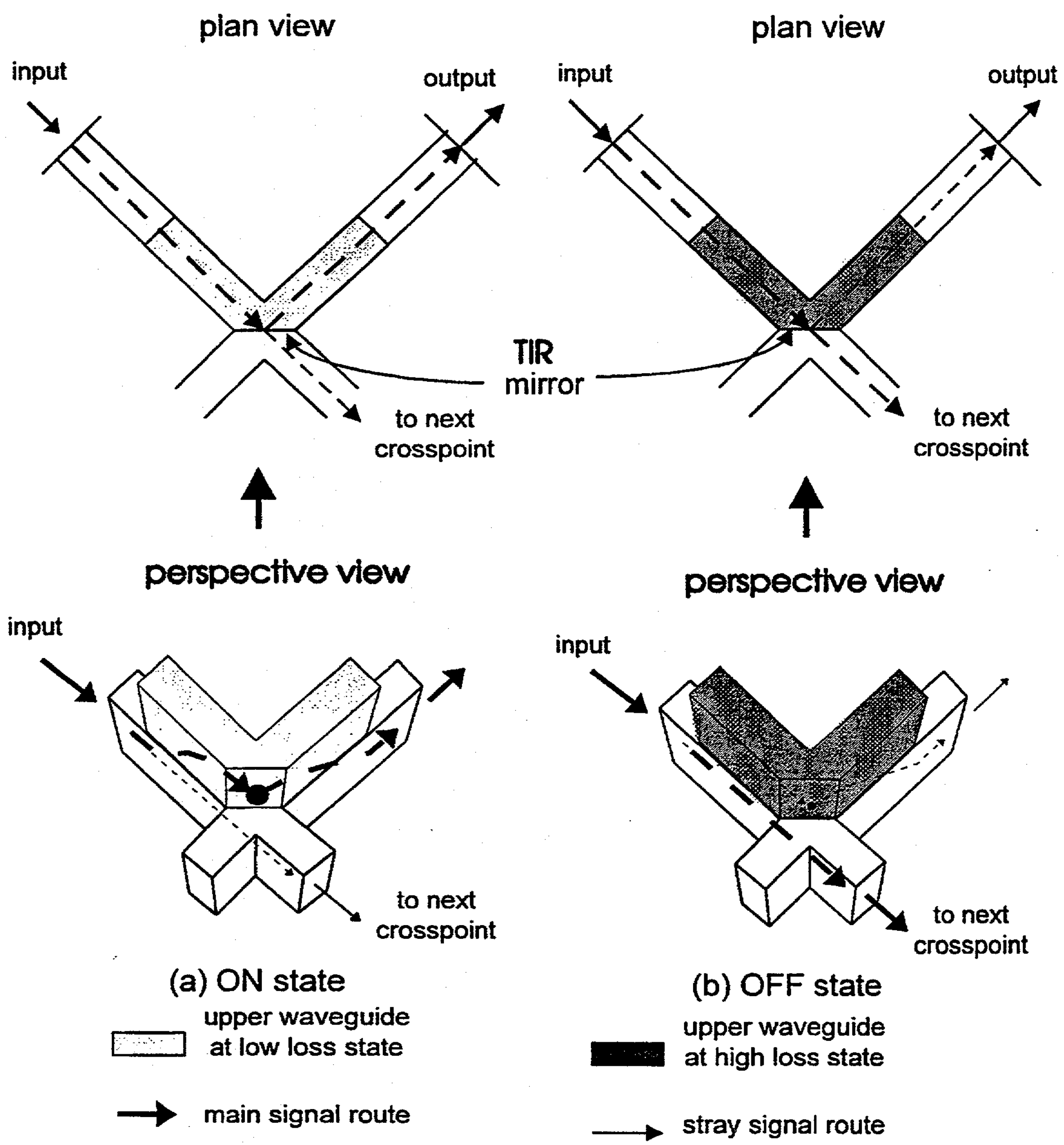
plan view
input
output
plan view
input
output
TIR
mirror
to next
crosspoint
to next
crosspoint
perspective view
perspective view
input
input
to next
crosspoint
to next
crosspoint
(a) ON state
upper waveguide
at low loss state
main signal route
(b) OFF state
upper waveguide
at high loss state
stray signal route

FIG. 2

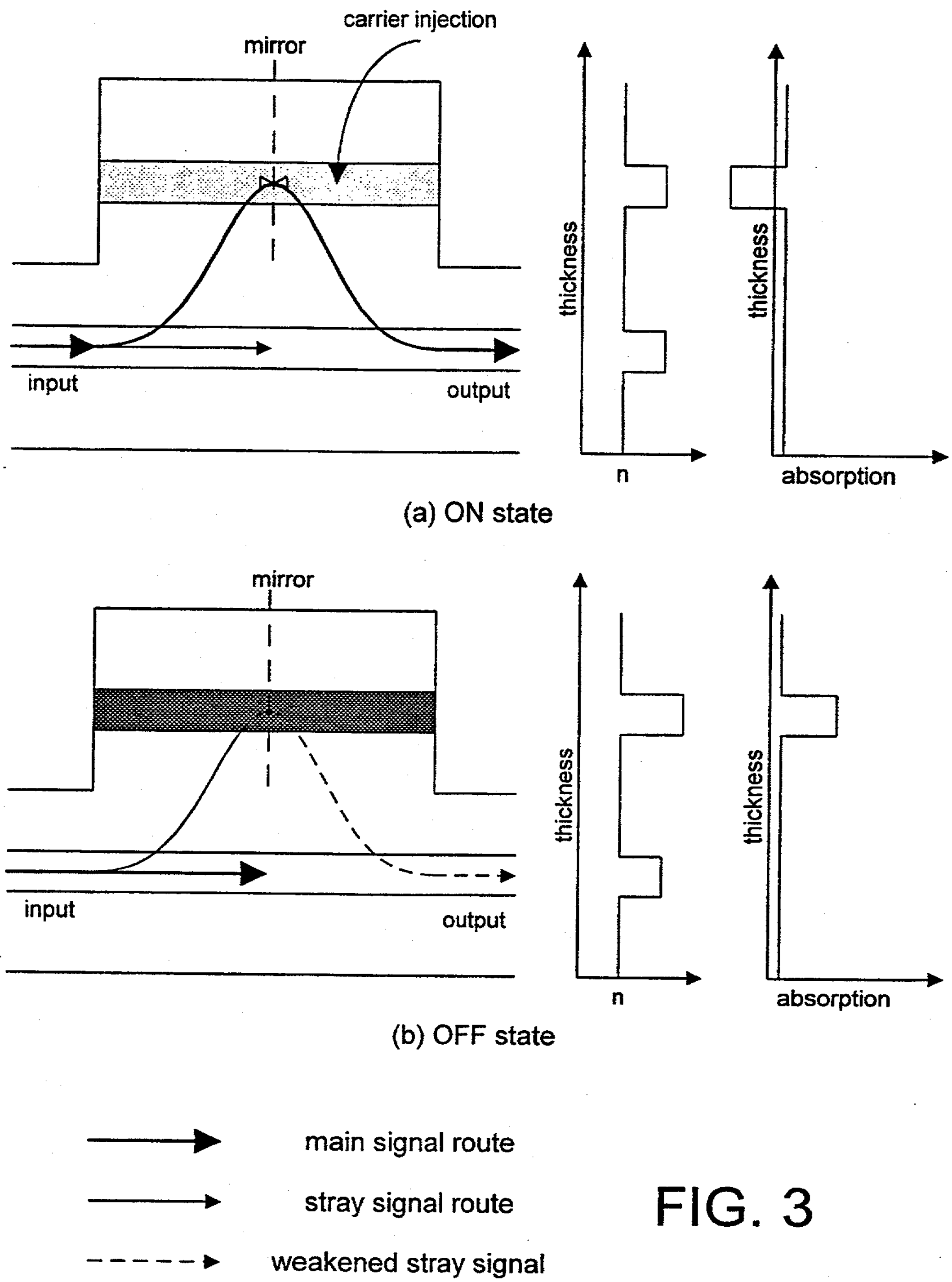
carrier injection
mirror
input
output
thickness
n
thickness
absorption
(a) ON state
mirror
input
output
thickness
n
thickness
absorption
(b) OFF state
main signal route
stray signal route
weakened stray signal

FIG. 3

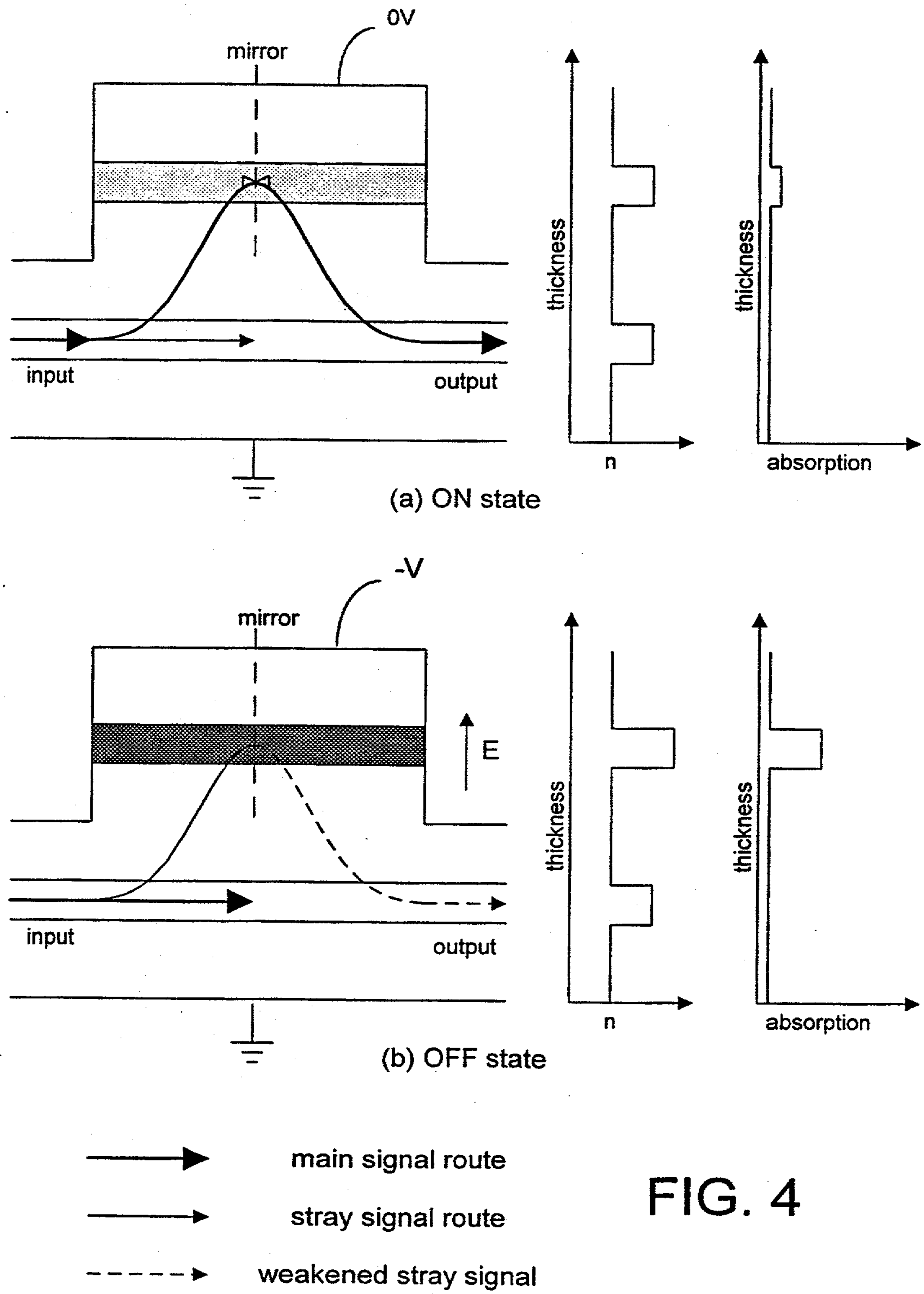
0V
mirror
thickness
thickness
input
output
n
absorption
(a) ON state
-V
mirror
E
thickness
thickness
input
output
n
absorption
(b) OFF state
main signal route
stray signal route
weakened stray signal

FIG. 4

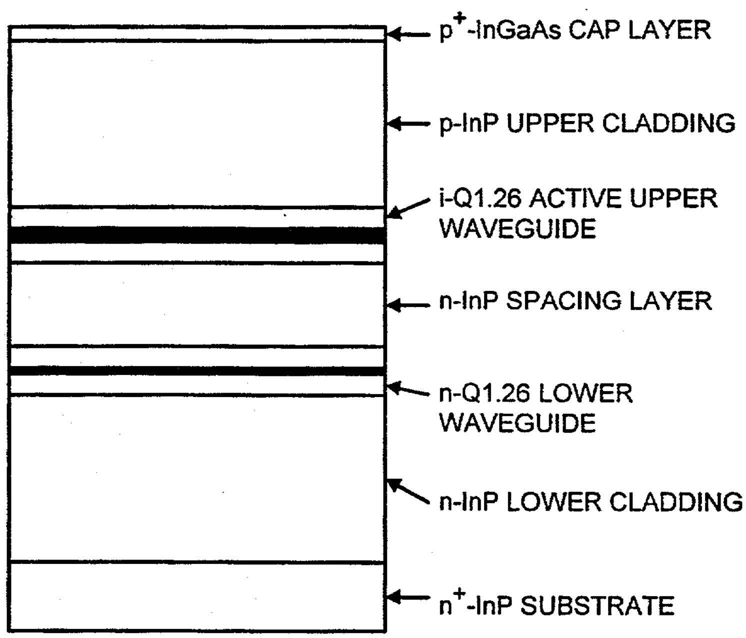
p+-InGaAs CAP LAYER
p-InP UPPER CLADDING
i-Q1.26 ACTIVE UPPER WAVEGUIDE
n-InP SPACING LAYER
n-Q1.26 LOWER WAVEGUIDE
n-InP LOWER CLADDING
n+-InP SUBSTRATE

FIG. 5

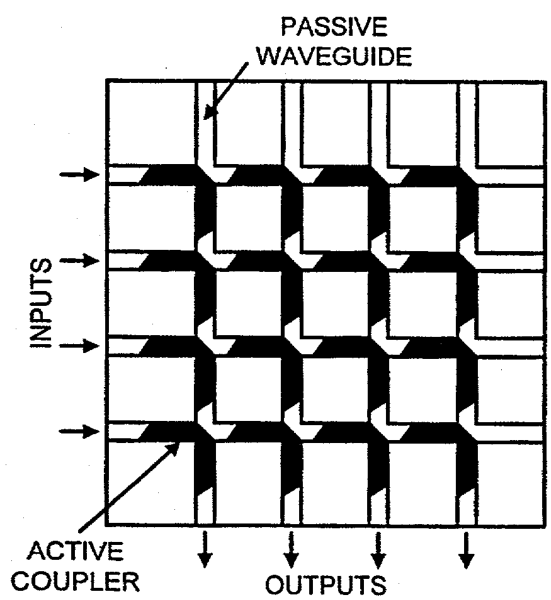
PASSIVE WAVEGUIDE
INPUTS
ACTIVE COUPLER
OUTPUTS

FIG. 6

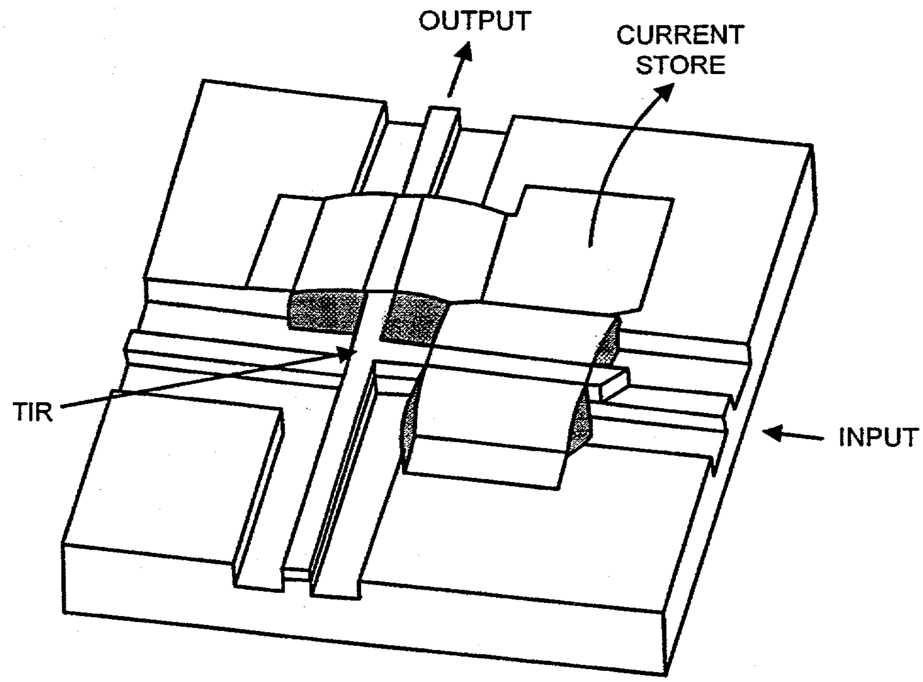
OUTPUT
CURRENT STORE
TIR
INPUT

FIG. 7

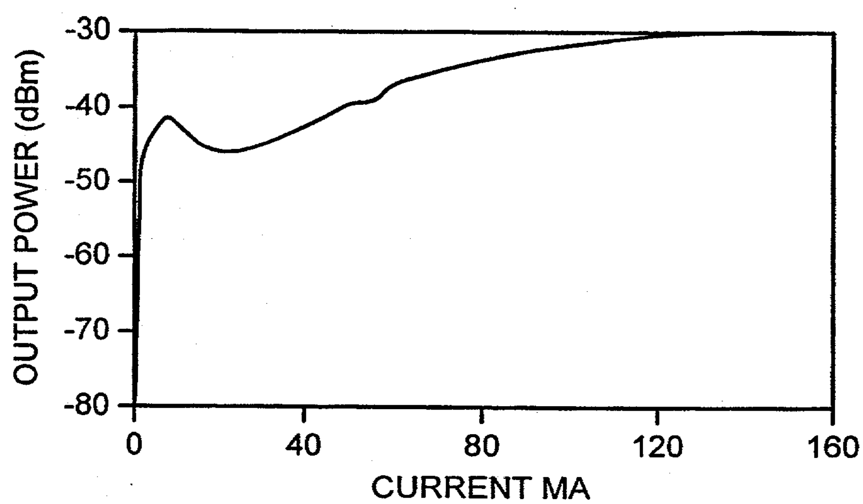
OUTPUT POWER (dBm)
-30
-40
-50
-60
-70
-80
0
40
80
120
160
CURRENT MA

FIG. 8

RULE 63 (37 C.F.R. 1.63)
DECLARATION AND POWER OF ATTORNEY
FOR PATENT APPLICATION
IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

As a below named inventor, I hereby declare that my residence, post office address and citizenship are as stated below next to my name, and I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

AN OPTICAL CROSSPOINT SWITCH USING VERTICALLY COUPLED WAVEGUIDE STRUCTURE

the specification of which (check applicable box(s)):

☐ is attached hereto
☐ was filed on ______ as U.S. Application Serial No. ______
☒ was filed as PCT international application No. PCT/GB00/01216 on 30 March 2000

and (if applicable to U.S. or PCT application) was amended on ______

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above. I acknowledge the duty to disclose information which is material to the patentability of this application in accordance with 37 C.F.R. 1.56. I hereby claim foreign priority benefits under 35 U.S.C. 119/365 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed or, if no priority is claimed, before the filing date of this application:

Priority Foreign Application(s):

Application Number	Country	Day/Month/Year Filed
9907407.2	Great Britain	31 March 1999

I hereby claim the benefit under 35 U.S.C. §119(e) of any United States provisional application(s) listed below.

Application Number	Date/Month/Year Filed

I hereby claim the benefit under 35 U.S.C. 120/365 of all prior United States and PCT international applications listed above or below and, insofar as the subject matter of each of the claims of this application is not disclosed in such prior applications in the manner provided by the first paragraph of 35 U.S.C. 112, I acknowledge the duty to disclose material information as defined in 37 C.F.R. 1.56 which occurred between the filing date of the prior applications and the national or PCT international filing date of this application:

Prior U.S./PCT Application(s):

Application Serial No.	Day/Month/Year Filed	Status: patented pending, abandoned

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon. And I hereby appoint NIXON & VANDERHYE P.C., 1100 North Glebe Rd., 8th Floor, Arlington, VA 22201-4714, telephone number (703) 816-4000 (to whom all communications are to be directed), and the following attorneys thereof (of the same address) individually and collectively my attorneys to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith and with the resulting patent: Arthur R. Crawford, 25327; Larry S. Nixon, 25640; Robert A. Vanderhye, 27076; James T. Hosmer, 30184; Robert W. Faris, 31352; Richard G. Besha, 22770; Mark E. Nusbaum, 32348; Michael J. Keenan, 32106; Bryan H. Davidson, 30251; Stanley C. Spooner, 27393; Leonard C. Mitchard, 29009; Duane M. Byers, 33363; Paul J. Henon, 33626; Jeffry H. Nelson, 30481; John R. Lastova, 33149; H. Warren Burnam, Jr. 29366; Thomas E. Byrne, 32205; Mary J. Wilson, 32955; J. Scott Davidson, 33489; Alan M. Kagen, 36178; William J. Griffin, 31260; Robert A. Molan, 29834; B. J. Sadoff, 36663; James D. Berquist, 34776; Updeep S. Gill, 37334.

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(3)
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